Open source and sustainability: the role of universities.

OPEN SOURCE AND SUSTAINABILITY: THE ROLE OF UNIVERSITY

Dr. Giorgio F. SIGNORINI, PhD
Dipartimento di Chimica, Università di Firenze
via della Lastruccia, 3
I-50019 Sesto F. (Firenze), Italy
giorgio.signorini@unifi.it

Abstract

One important goal in sustainability is making technologies available to the maximum possible number of individuals, and especially to those living in less developed areas (Goal 9 of SDG). However, the diffusion of technical knowledge is hindered by a number of factors, among which the Intellectual Property Rights (IPR) system plays a primary role. While opinions about the real effect of IPRs in stimulating and disseminating innovation differ, there is a growing number of authors arguing that a different approach may be more effective in promoting global development. The success of the Open Source (OS) model in the field of software has led analysts to speculate whether this paradigm can be extended to other fields. Key to this model are both free access to knowledge and the right to use other people's results.

After reviewing the main features of the OS model, we explore different areas where it can be profitably applied, such as hardware design and production; we then discuss how academical institutions can (and should) help diffusing the OS philosophy and practice. Widespread use of OS software, fostering of research projects aimed to use and develop OS software and hardware, the use of open education tools, and a strong commitment to open access publishing are some of the discussed examples.

Keywords Sustainable Development, University, Open Source, Open Education, Open Access

1 Introduction

What is sustainability about? According to the widely accepted definition of the Brundtland Report (Brundtland 1987), human development is sustainable when it can satisfy the needs of the current generation without compromising the ability of future generations to do the same. This is the original approach, which puts the focus on *resource consumption*; for example, it is evident that using renewable sources for the production of energy is sustainable, while consuming exhaustible fossil fuel reserves is not.

However, it has long been recognized that there are many aspects of human growth, other than the depletion of natural goods, that can be not sustainable (Brandt 1980, 1983; Quilligan 2002): among them, uncontrolled population growth, the rush to armaments, an ever-rising debt of poor nations. Less obviously, other issues such as unequal distribution of wealth or the discrimination of women are also seen as non-sustainable, simply because they inevitably lead to social and political instability. In the course of years, the sustainable development objectives promoted by the United Nations, first in 1992 ("Agenda

21"), then in 2000 ("Millennium Development Goals") and again in 2015 ("Sustainable Development Goals", SDG (United Nations 2015)), have come to include more and more economic and social issues.

One of the SDGs (goal 9: "Build resilient infrastructure, promote sustainable industrialization and foster innovation") directly involves the transfer of technology ("innovation") to less developed countries. It is hard to overlook the striking contrast that currently exists between the high level of technology reached by humanity as a whole and the large fraction of people having no access to it (Pearce 2012); think of life-saving drugs which major pharmaceutical companies hold the patents of, or of the technical/scientific literature that is only published on expensive journals most educational institutions in the Third World cannot afford to buy. Indeed, the lack of access to, and command of, technology has been described sometimes as the *main* weakness of developing countries ((Brandt 1980), cited in (Quilligan 2002)).

It is a fact that one of the obstacles, perhaps the most effective one, to the diffusion of technology is represented by the regulations protecting the so-called Intellectual Property Rights (IPR). Opinions about how effective IPRs are in promoting and disseminating technical innovation differ (see, for example, (Blind 2012) and references therein). The traditional view has been that IPRs are required in order to secure a form of reward for the research investment. However, in recent years there has been a growing number of studies suggesting that a different paradigm may be more effective in fostering innovation (Weber et al. 2000; Boldrin et al. 2009; Henry and Stiglitz 2010; Boldrin and Levine 2013; Daley 2014; Stiglitz and Greenwald 2015).

There are two main ways IPRs can hinder development of poorer nations: by limiting people's access to knowledge through copyright, and by restricting the use of novel technologies through patents. Thus, an alternative model should be able to address both issues.

What is commonly known as Open Source Software (but is more appropriately termed FLOSS, see below), has challenged the current production paradigm in the area of information technology by explicitly tackling these two aspects. Note that the expression "Open Source Software" (OSS), in fact, only implies removing the first of the two obstacles, regarding *availability*; however, in the general parlance, it also encompasses the *right to use* the accessed resource. The success that OSS has seen in recent years (Bonaccorsi and Rossi 2003) has led many authors to suggest that the Open Source (OS) scheme be exported to other areas, such as hard technologies, to favor their advancement.

"Open Source Hardware" (OSHWA 2012) and "Open Design" initiatives are attempts in this direction, that have contributed both the theoretical framework of the approach and concrete examples of how it can be implemented and sustained (Li et al. 2017). The "Open Access" movement advocates free access to (and use of) any kind of intellectual work, including the scientific and technological literature, which can stimulate innovation in less developed countries. Educational institutions are increasingly investing in "Open Education" programs. Despite the rich literature that exists on these subjects, few authors have tried to discuss in a unified, comprehensive fashion the concept of "openness" in such different contexts (Pomerantz and Peek 2016; Aksulu and Wade 2010). The present paper is an attempt to fill in this gap, with special emphasis on what elements of the OSS model are retained in each, and on their implications with respect to sustainable development.

A second point of this work derives from the observation that key to the diffusion of the OS paradigm to new areas is how it is perceived by the public. OSS has been traditionally viewed by the general opinion as only a cheap alternative to quality products, but recently this perception is changing, with a growing interest in OSS by companies and public administrations (Roumani et al. 2017; Casson and Ryan 2006). Obviously the education and research world plays a primary role in this change of perspective (Coppola and Neelley 2004; Bacon and Dillon 2006; Lakhan and Jhunjhunwala 2008; O'Hara and Kay 2003; Pankaja and Mukund Raj 2013), because they can not only illustrate the advantages of these products or the ethical motivations that are at the roots of the philosophy, but also support OS with working

examples. The effort that universities will be able to put in this field can likely make the difference.

In the following, a review of the main features of OSS is presented first; then, in the central section, a number of possible areas of application of the "Open Source" model are analyzed; finally, we discuss the role of university in promoting the diffusion of the Open Source model.

2 Open Source Software

2.1 "Open Source" vs. "Free" (or, use "FLOSS" regularly)

As anticipated above, although the designation "Open Source Software" has gained widespread acceptance by now, it is very misleading. In almost all contexts, in fact, it is applied to software that can be not only accessed freely but also legally used and distributed; that is, basically, what the early (circa 1985) definition of "Free Software" by Richard Stallman and the Free Software Foundation (FSF) (FSF 2017) established:

> A program is free software if the program's users have the four essential freedoms:
>
> - The freedom to run the program as you wish, for any purpose (freedom 0).
> - The freedom to study how the program works, and change it so it does your computing as you wish (freedom 1). Access to the source code is a precondition for this.
> - The freedom to redistribute copies so you can help others (freedom 2).
> - The freedom to distribute copies of your modified versions to others (freedom 3). By doing this you can give the whole community a chance to benefit from your changes. Access to the source code is a precondition for this.

Note that here the stress is placed on freedom, the rights that are granted to the user. While freedom 0 may sound rather obvious, in analogy with what one is entitled to do with any device they may obtain, freedom 1 is a little more problematic. Think of a buying a small appliance: you surely have the right to inspect and possibly modify it, but in practice you can't, because the operation of an increasing number of them relies on instructions coded in electronics, which are difficult if not impossible to understand. This is where the concept of openness comes in: openness is a necessary requirement to enable the owner to fully control their device. Freedoms 2 and 3 give the user the right of reproducing the item, something that is usually not permitted with real objects, at least with those covered by patents.

On the other hand, it is to be remarked that nothing about the costs ("think of 'free speech', not 'free beer"' (FSF 2017)) is implied by the above definition; this kind of software can be profitably traded - in just about the same way that a bottle of water from a mountain creek can. To disambiguate between the two different meanings of the English word "free", the terms "gratis", as opposed to "libre", are sometimes used.

In spite of these important semantic distinctions, "Open Source" has now come to assume a much broader meaning than the words encompass, especially so after the founding (1998) of the Open Source Initiative (OSI). OSI's now widely recognized definition of Open Source Software (Perens et al. 1999; OSI 2007) closely resembles the one by the FSF:

> Generally, Open Source software is software that can be freely accessed, used, changed, and shared (in modified or unmodified form) by anyone (OSI 2018)

There are still some fine differences between FSF, OSI, and other definitions, which however are not relevant in this context. Perhaps the best designation for this technology is the *portmanteau* "Free (Libre),

Open Source Software" (FLOSS), which, if somewhat redundant, effectively transmits the notions of both freedom and openness.

2.1.1 Copyleft

The legal frame for distributing FLOSS is a set of licenses that protect the basic freedoms of the user. The one that FSF propose and use for their software, such as the GNU suite which is an essential part of the GNU/Linux operating system, is the so-called "copyleft" (where the second half of the word contrasts the one in "copyright"): copylefted software is subject to distribution terms that ensure that copies of that software carry the same distribution terms. The license that formally details these terms is the GNU General Public License, or GPL.

2.2 Features

The distinctive features of FLOSS are direct consequences of the basic properties that define FLOSS (in either the FSF or the OSI version, see above), and ultimately of the two basic rights: the right to *access* and the right to *actively use* it.

2.2.1 Quality

The first issue regarding FLOSS is about its general quality.

There is a widespread view that "since Open Source software is free, it must be of low quality". This idea is deeply rooted in our everyday experience: quality goods have high prices and their ownership is strictly protected.

In fact, it turns out that in many cases the performance of FLOSS is comparable or superior to that of their proprietary counterparts. Studies of the last two decades have shown many FLOSS products to be highly **reliable** (in the sense of both "stable" and "secure"), and in many cases to outperform proprietary systems (Miller et al. 1995; Boulanger 2005). Another feature that adds to the quality of open-source software is its high degree of **flexibility**, which means both that it can be easily customized (Krishnamurthy 2005) to meet different or new needs, and that it can be very resilient to changes in the environment.

While it may be not easy to precisely define the "quality" of software products, there are some valuable -if indirect- measures of it: for example, the level of diffusion of OSS, and the motivations that drive its adoption.

There are not many surveys of general scope regarding the popularity of OSS; most data deal with network applications, which can be easily monitored. It is known, for example, that among web server programs and the underlying operating systems, FLOSS usually ranks first (Wheeler 2015). Results vary considerably and depend, among other things, on country, activity sector, size of organization (Ghosh et al. 2002; Picerni and De Rossi 2009; Wheeler 2015); however, the fact that open source solutions occupy a significant share of the market, especially in the field of server systems, is universally recognized, as is the fact that their popularity is constantly rising.

"Quality of solutions" and "competitive features and technical capabilities" are cited in a recent survey (Black Duck 2016) as the first two reasons why experts adopt open source. According to another study (Roumani et al. 2017) the three main sources of trust in enterprise-OSS are: conformation to open standards; security; service. Rather unexpectedly, in almost all reports cost does *not* emerge as the main motivation behind the choice of adopting FLOSS. In fact, open products prove cheaper than proprietary ones, in general, only if the total cost of ownership (TCO), rather than the sheer cost of adoption, is

considered. Users are preferably attracted by other positive features, such as stability, security, user experience, compatibility, transparency, customizability (Zlotnick 2017), and also the availability of service (Benkler 2006). We will discuss these aspects in the following.

As a whole, we can safely state that there are many FLOSS products that are of very good quality, although this is, obviously, not automatically true of *all* FLOSS.

2.2.2 Reliability

By design, in an open source project there is no limit to the number of contributors, with every user being a possible developer, and popular projects involving thousands of them (OpenHub 2018). It is a now generally accepted view that a large community performing the revision and test process provides fast and efficient bug fixing, vulnerability checking, performance refinement; as early as in 1999, Eric Raymond in his seminal essay *The Cathedral and the Bazaar* (Raymond 1999) was boiling this concept down to

> "Treating your users as co-developers is your least-hassle route to rapid code improvement and effective debugging"

2.2.3 Flexibility

The diversity of the environments where open source programs are developed and used, and the fact that most people that support FLOSS are both users and developers is also at the roots of its great flexibility (Roumani et al. 2017). Localization, implementing of new features, adapting tools to changed conditions: all these tasks are more easily carried out by a sharing community than by a small number of hired experts who must respect the secrecy and patent restrictions as is typical of commercial software firms.

2.2.4 Innovation and learning incentive

It has been noted that the open source model also has a greater potential for innovation (e.g., for filling unfilled market areas (Boulanger 2005)). New ideas are best fostered in a free and knowledge-sharing environment(Gloor 2006). It is a fact that many of the tools that have made the revolution of the ICT world in the last decades, such as Internet and Internet applications like electronic mail and the WWW, the Android-based smartphones, and Wikipedia, were based -if not on open-source software in a strict sense- on open standards and/or shared technologies. Using Raymond's words again (Raymond 1999),

> "the root problem of innovation (in software, or anywhere else) is [...] fundamentally [...] how to grow lots of people who can have insights in the first place."

that is, it is by reaching widest possible diffusion of knowledge, and not by restricting it with IPRs, that we can favor innovation.

2.2.5 Collaborative scheme

Many FLOSS advocates claim that the main value of it lies in the production method itself. Setting up work in a way that is "radically decentralized, collaborative, and nonproprietary; based on sharing resources and outputs among widely distributed, loosely connected individuals who cooperate with each other" (Benkler 2006) is indeed a radical change from the traditional, hierarchically organized and competition-driven, perspective. Some authors have long questioned the validity of the widely accepted assumption that setting people "one against the other" is the best way for boosting production –let alone living happily (Kohn 1992, 1987; Stiglitz and Greenwald 2015). FLOSS provides a real-world example

of how work can be organized in a totally different way from the traditional one and still be as efficient –or even more.

Thus one of the advantages of using FLOSS is of a social nature: it promotes changes in society that may help build a more sustainable world.

2.2.6 Independence from vendor

From the user point of view, proprietary software often has the undesirable effect of forcing clients to keep using the same software even when it no longer meets their original needs. This is due to the use of proprietary formats or tools that cannot be exported to a different platform, perhaps as the result of an aggressive fidelization policy of the vendor.

FLOSS has no blind spots. Migration to a new software is always possible because users have full control of algorithms and data. In some cases this process may be painful, but it is likely that the community will come to help with compatibility and conversion software. And this will be so forever, while a discontinued proprietary software may result in your resources becoming unusable with its secret machinery buried in some unaccessible archive, or lost for good.

Freedom from vendor lock-in (Roumani et al. 2017) is especially desirable in the public sector (Casson and Ryan 2006).

At the opposite end of closed technology lies the system of **open standards**. FLOSS spontaneously encourages the formation of standards (Weber et al. 2000), which can have beneficial economical effects. Firms may choose to adopt FLOSS to help "development of open standards and discourage establishment of a proprietary one" (Bonaccorsi and Rossi 2003) by some competitor.

2.2.7 Low cost

FLOSS can be distributed at lower prices than commercial products, as a consequence of reduced costs of both production and marketing. As already pointed out, FLOSS does not necessarily come at no cost: storage media for recording the program, shipping, and the like, do require some expense, and can be conveniently provided by some distributor –which, as a side-effect, opens a market opportunity for new initiatives.

As we have seen, low cost does not represent the main motivation in the adoption of FLOSS by companies or professionals; however, it can have nonnegligible, beneficial effects on their budgets.

2.2.8 Service

Support services are perceived by companies as an essential requirement of software products (Benkler 2006). On the one hand, often proprietary software suppliers also offer support contracts (usually reliable), while FLOSS distributors do not necessarily have the expertise to provide that service. On the other hand, again, since there is no restriction on studying FLOSS, it can be potentially serviced by anyone –especially the developers themselves. Actually this represents a very good opportunity for "the emergence of local capabilities to provide software services" (Benkler 2006)

3 The OS model and its possible applications

Perhaps the best way to summarize the above discussion in view of the first point of this paper is the following sentence:

> "Now that Open Source has come of age, the question is not: Is it better than closed software? But rather: To what other systems, outside of software, can we apply the concepts of Open Source and public ownership?" (Aragona 2005)

More specifically, we want to ask ourselves:

- can the OS model be exported to *hard* technologies? and perhaps, in a broader sense, to the domains of content publishing and education?
- which of the defining properties of FLOSS can also be applied to these areas?
- what are the differences?

Note that key to any OS project are: a network infrastructure through which contributors can share their work and ideas; a sound system of governance that effectively channels activity into the target product; a software platform that implements such a system (Bonaccorsi and Rossi 2003).

3.1 Open Source Hardware

There is one obvious difference between hardware and software production: software, as opposed to hardware, is immaterial. To obtain and use a computer program everything that is needed is some digital storage, a very cheap resource; on the contrary, the building of a technical equipment always requires a certain amount of starting materials that must be supplied by the user, generally at non-negligible costs.

Clearly, open-source hardware is not about sharing the ownership of physical devices or tools; it is about free access only to their *immaterial* part, namely blueprints, methods, all the know-how needed. As we have seen, the necessary and sufficient conditions of the OS model are knowledge sharing and the right to actively use it.

The idea of "Open Design" is basically that of directly projecting the principles of FLOSS onto the world of machinery and manufacturing processes (Vallance et al. 2001), as an alternative to the proprietary design scheme and with the same motivations as open-source software: favoring innovation, quality and accessibility of products through collaboration of experts and users alike. The Open Design Foundation has established an "Open Design Definition" (Open Design Foundation 2000) and terms of use that closely resemble those of FSF (Vallance et al. 2001):

- documentation of a design is available for *free,*
- anyone is *free* to use or modify the design by changing the design documentation,
- anyone is *free* to distribute the original or modified designs (for fee or for free), and
- modifications to the design must be returned to the community (if redistributed).

Similar "Open Source Hardware" definition and principles have been provided by the Open Source HardWare Association (OSHWA) (OSHWA 2012)

3.1.1 Open Source Appropriate Technologies

Experience of the last decades has shown that the ideas of OSH can be successfully applied to the area of the so-called "Appropriate Technologies" (AT). Originally proposed (Schumacher 1973) as a response to the evidence that cutting-edge, sophisticated technologies produced by the highly developed nations usually promote very little advance in the quality of life of the majority of world population (low income

classes and/or countries), ATs can be defined as "technologies that are easily and economically utilized from readily available resources by local communities to meet their needs" (Pearce 2012); they are "appropriate" with respect to the regional size of the economy which they are supposed to help (Schumacher 1973) and which is seen as the ideal size for the development of those parts of society who need it most.

As it has been pointed out, "more than 10 million children under the age of five die each year from preventable causes", in spite of the cures being well known, just because they are not available economically (Pearce 2012).

Small size and limited complexity are key features of ATs. However, some technologies, even very basic ones, may still be inaccessible to under-privileged communities not so much because of their cost, as because of the lack of the knowledge needed to use and maintain them: think of a patented device which may be operated only by skilled professionals licensed by the manufacturer (Mushtaq and Pearce 2011). Open Source Appropriate Technology (OSAT), patent-free AT which everybody may copy the design of, fits well in this scenario, and is aimed at cutting monopoly/royalty costs while giving users-developers full control over their equipment (for example, allowing them to incorporate a small apparatus in a larger one).

The infrastructure supporting OSATs usually takes the form of an open clearinghouse, like Appropedia (Appropedia 2018), storing all the instructions for building the solutions proposed. Not surprisingly, Appropedia is based on MediaWiki software (see above) and its content is licensed under a Creative Commons BY-SA license (see below).

3.1.2 Manufacturing

As the Open Design movement shows (Vallance et al. 2001; Li et al. 2017), open-source machinery does not necessarily have to be simple. With automated manufacturing, rather complex devices can be assembled, using publicly available instruction sets. A big step forward in this field was made since the appearance of 3D printers on the market.

The RepRap (Replicating Rapid Prototyping) project (Jones et al. 2011), for example, is based on one 3D printer that can (almost) replicate itself, being able to print the majority of its own parts, and is intended as an open source, low-cost manufacturing machine. In principle, such machines should enable any individual to autonomously build e.g. many of the artifacts used in an average household, on a path of increasing independence of people from large-scale manufacturing corporations. The potential impact of this process on global economy is evident.

Among many similar initiatives, one of more general scope is Open Source Ecology (Stokstad 2011), whose declared goal is "to create an open source economy – an efficient economy which increases innovation by open collaboration".

OSE flagship project is the Global Village Construction Set (OSE 2018), a collection of open-source instructions for building what they think is the minimum set of 50 tools needed by "an entire self-sustaining village": from a tractor to an oven, to a circuit maker, to power production stations. These include fabrication and automated machines that make other machines –an analogue of 3D printers with a broader purpose.

3.1.3 Examples

As a representative example of Open Source Hardware we may take the Arduino board (Arduino 2018; Badamasi 2014). Arduino is a line of open-source electronic platforms with micro-controller for the remote control of devices.

A wealth of Open Design / OSAT projects making use of Arduino have been implemented. We encourage readers to visit any OSH clearinghouse to appreciate the diversity of applications this modular hardware can be adapted to.

Arduino can also be taken as a working example of how OSH can be profitable; this is the subject of next section.

3.1.4 Business model

It is natural to ask ourselves how developers of OSH can make a profit from their work, given the lack of IPR-related revenues.

First of all (and differently from FLOSS) the physical realization of products accounts for an important share of hardware business, as does its marketing. The design phase, on the contrary, is usually not the main activity, so it is not not strictly necessary for it to be profitable in itself. Consider that there is no sharp boundary between developers and manufacturers: companies and professionals often play both roles at the same time.

Secondly, manufacturers of OSH have several competitive advantages: they don't have to pay for patents; they get an efficient user feedback for free; their services like customer care or localization are highly valued, since, as active developers, they know their product well (Thompson 2008).

Arduino inventors and original makers, who decided to put its design in the open for everybody to read, find that their product is still more requested than the cheaper models manufactured by factories all over the world using the open blueprints (Thompson 2008). This is because Arduino's original items turn out to be higher quality; and since the development process, that has their company as the primary hub, is always in progress, they find themselves always one generation ahead of their (non-)competitors.

3.2 Open Access

We see that the patents system acts as a barrier to free access to knowledge, and consequently to the diffusion of technology to less-developed areas of the world. The same effect is caused by another class of restrictions, namely the copyright laws.

In response to copyright, an Open Access philosophy has emerged. As the 2002 manifesto of a group of leading academics, chief librarians, and information officers puts it, "Removing access barriers to ... literature will accelerate research, enrich education, share the learning of the rich with the poor and the poor with the rich, make this literature as useful as it can be, and lay the foundation for uniting humanity in a common intellectual conversation and quest for knowledge." (BOAI 2002)

3.2.1 Scientific literature

Let us focus on academic publications first. It is a fact that people outside the research institutions have virtually no access to up-to-date technical and scientific literature covered by copyright –even when they do not involve patents. Journal and books presenting new ideas and discoveries, essential for stimulating innovation, usually come at a forbiddingly high price for an individual or medium-sized business. Expenditures of research libraries for bibliographic materials have been steadily increasing in the last years (ARL 2018). Indeed, a fairly large number of universities have long declared that they can no more afford to buy journal subscriptions (Sample 2012). Robert Darnton, the past director of Harvard Library, once declared in an interview: "We faculty do the research, write the papers, referee papers by other researchers, serve on editorial boards, all of it for free ... and then we buy back the results of our labor at outrageous prices." (Sample 2012)

The reason for the hyper-inflation of the costs of scientific journals is simple: publishers operate in a basically monopolistic regime (Shieber 2009; Björk and Solomon 2014) and can impose whatever price they set. Moreover, the academic career system, based on publications, virtually obliges scholars to publish at any cost, thus consolidating the monopoly.

There is also the important question of whether it is fair to restrict access to the results of research that is publicly funded. This amounts to using taxpayers' money to subsidize a monopoly (Boldrin et al. 2008). The U.S. National Institutes for Health (NIH) and its Canadian analogue CIHR (Mushtaq and Pearce 2011) have reacted to this by requiring that the results of the research they fund be made available to the public.

Open access to publications is emerging as a solution to this. The rationale is that the cost of publishing can be payed by the authors in order to make their articles readable for free (Shieber 2009), a mechanism that can easily be imagined to lower the overall costs per publication (Odlyzko 1997; BOAI 2002). However, the Open Access (OA) journals market system has drawbacks too. Article processing charges (APC) are still rather high, of the order of 1500$ per article (Shieber 2009), which sounds as a comparatively large proportion of the total costs of a research project. Many of the major journals, instead of switching to OA completely, maintain a hybrid regime, both OA and subscription based, so that in the end there is no significant reduction of costs for research institutions. The academia has witnessed the birth of open-access "predatory" publishers, that leverage on the researchers' need to have their articles published, but are of very low quality and often border on fraudulent behavior (Pisanski et al. 2017). This is an area of ongoing evolution and it may be still too early to assess the efficacy of OA publishing.

There is a number of spontaneous initiatives aimed at contrasting the current obstacles to free access to scientific literature. Many scientists, for example, are familiar with Sci-Hub (Bohannon 2016), a platform created by Kazakhstani student Alexandra Elbakyan who strived to get over the paywalls to the papers she needed to complete her thesis.

3.2.2 Alternative to copyright

One can argue that open access not only to scientific and technical literature, but to *all* kind of content, including literary and artistic creations, is beneficial to development. Indeed, there is evidence that, while copyright laws limit the diffusion of intellectual work, on the other side they have not had the alleged effect of increasing the production of books and music (Boldrin et al. 2008). Whether a wider diffusion of cultural products can contribute to human development is, certainly, a debatable subject, and one that is beyond the scope of this article. It is, nonetheless, worth noting that the dissemination of culture -be it an invention, a painting or a novel- is strictly connected to freedom and human rights, and thus, ultimately, to the advancement of society.

The alternative to property is the commons (Hess and Ostrom 2007). Several formal, legal schemes have been devised as alternatives to the traditional copyright model, the most prominent being the Creative Commons (CC) licenses. These modular licenses allow authors to reserve *some* (as opposed to *all*) rights for themselves, such as the moral right to be recognized as the original author of the work. Together, the CC licenses make up the legal frame in which cultural works can be safely distributed while still being protected against unlawful appropriation by others (individuals or companies).

At the opposite end of the copyright regime there are Free Cultural Works, and the reader will not be surprised, by now, to learn that the formal definition of FCW issued (Möller 2008) by the organization "Freedom Defined" matches the FSF definition of Free Software almost exactly:

by freedom we mean:

- the freedom to use the work and enjoy the benefits of using it
- the freedom to study the work and to apply knowledge acquired from it
- the freedom to make and redistribute copies, in whole or in part, of the information or expression
- the freedom to make changes and improvements, and to distribute derivative works

Note that not all CC licenses fall into this definition. Namely, the "non-commercial" and "no-derivatives" clauses of CC are more restricting than this (Hagedorn et al. 2011). The free content movement contends that imposing a non-commercial use license on one's work is "very rarely justifiable on economic or ideological grounds" since it "excludes many people, from free content communities to small scale commercial users", while "the decision to give away your work for free already eliminates most large scale commercial uses"; and that those authors who want to promote widespread use of their content should instead use a "share-alike"-type license like Wikipedia (Möller 2007)

4 The path to an open -and sustainable- university

The picture that emerges from the previous section is that the Open Source model can be extended from software to other fields of human activity by applying analogous principles, this process being expected to provide similarly beneficial effects towards the diffusion of knowledge and technology and thus to contribute to sustainable development.

It is not surprising that the educational domain has shown a growing interest in the subject (Carmichael and Honou 2002; O'Hara and Kay 2003; Lakhan and Jhunjhunwala 2008). This is because of both the social, economical and cultural implications of the OS model, on one side, and the actual innovation that it can bring into the teaching and research tools and processes on the other side. We have stressed the former aspect in many places of the above sections, and will come back to this point when discussing an "open university" road-map below. Initiatives aimed at developing the latter aspect come under the generic name of "Open Education" and are reviewed in the next subsection.

4.1 Open Education

Openness is, obviously, at the very core of the learning process: learning is about exploring things freely, looking at how they work, and perhaps disassemble and assemble them again. But not everything is as open as it seems, in the educational world. What can be called the "Open Education" (OE) movement has put in its agenda a number of fields of action which have the objective of increasing openness in schools and universities.

4.1.1 Use of non-proprietary tools

The technological development of the last decades, largely based on non-free platforms, has led us to accept as natural for the tools used in teaching to be patented or copyrighted. While this seems reasonable for e.g. some courses which need sophisticated instruments, the wide use, in schools, of proprietary software/hardware for which there are open-source equivalents is highly questionable. In fact, the scholar system should, in principle, help students acquire universal skills rather than become familiar with one particular product (and likely, be a future paying user of it) .

Thus, one primary issue for proponents of OE is, simply, supporting the use of non-proprietary tools in education. The motivation here is not so much that of reducing costs, as that of increasing **school neutrality** with respect to the market. It has been noted that "training young people and making them more aware of different computing systems has been beneficial for their learning" (Bacon and Dillon 2006).

4.1.2 Collaborative environment

One of the key features of the Open Source model can be profitably applied to the learning process, namely its acting as an incentive for collaboration. Since anyone can join in the modification of OS tools, teaching projects that make use of them are very easy to implement (Pearce 2007; Arduino 2018); students can, for example, develop a new functionality of some OS software or device, or add new content to some shared cultural work (think of Wikipedia), working together as well as with people at the other end of the world (one example of this is the "Google Summer of Code" initiative (Google 2016)).

We have already mentioned the view that competition of disconnected individuals should not be assumed as the best way of stimulating production. In the educational world, working in a connected environment is usually considered as a way of "encouraging young people, in particular, to develop new, creative, and different forms of communication and knowledge creation outside formal education"(Kop and Hill 2008). Many educators, well before the advent of digital networks, have argued that by peer-reviewing the work of one another, students can achieve a higher level of knowledge than in the traditional, top-down approach (Scardamalia and Bereiter 1991).

Similarly, use of OS tools in the classroom, by encouraging teachers to share their experiences, can be instrumental in the promotion of teacher education; by adopting a collaborative scheme, they may build up an efficient "community of practice" (Bacon and Dillon 2006).

4.1.3 Open Education resources

From a slightly different perspective, teaching material can be made open-access and shared on the Internet, possibly following a wiki-like scheme. "Open courseware" was initially intended as a supplement rather than as a substitute of traditional course material, and its parallel with open source software was explicit (Long 2002). There are now a number of platforms for creating and using OA courseware, or, more generally, Open Education Resources (OER) (Butcher 2015); see for example the Open Education Consortium (OEC 2018), Open Education Europa (OEE 2018), the OER Commons (OER Commons 2018), and Opensource.com (Opensource.com 2018). Advantages of OER are -once again- a more efficient use of resources (teachers can translate or adapt other teachers' material without having to start from scratch or face the copyright limitations), reduced costs for students, and the possibility of expanding the subjects touched in the classroom with a library of supplementary materials. It is evident how valuable OERs can be in promoting less-favored populations' access to knowledge.

An important class of OERs are **Massive Open Online Courses (MOOC)**, courses that can be completely administered through the Internet and enable institutions to reach a much larger audience than traditional classroom courses. A group of high-class university partners led by MIT, Harvard and Berkeley, is giving life to the edX Consortium, in their own words a "MOOC provider that is both nonprofit and open source" (edX 2018).

4.2 The role of university

One of the main points of this paper is to discuss how universities can help promote the Open Source model in its many different aspects and applications, thus contributing to global sustainability. In the preceding subsection, dealing with Open Education, several ways of interaction between the scholar system and Open Source have been outlined; in the following we illustrate, in a schematic way, the lines of action that Universities can adopt in order to help OS gain weight and attention.

4.2.1 Support the Open Source philosophy

It has been noted that the public discourse accompanying OSS can influence the diffusion of this technology (Marsan et al. 2012). Clearly, besides IT specialists, higher education institutions have a primary role in transmitting a positive or negative attitude towards OSS.

It is especially so because, as we have seen, OS is not simply a new technology, but rather a new way of producing and sharing technology and knowledge in general. The "commons based" scheme of production (Bacon and Dillon 2006) has been the subject of an intense academic debate in the last decades (Benkler 2002), with contributions from many political economy scholars including Nobel laureate Elinor Ostrom (Hess and Ostrom 2007). In this respect, universities can be very influential. By taking a clear stance in favor of the OS -but even only by acknowledging it as a legitimate issue in the academia!- they will contribute to advancing a positive perception of OS against the conventional wisdom "no cost–no quality".

There are many opportunities for academic institutions to underline the positive features of the OS approach we have outlined above (reliability; flexibility; incentive for collaboration, learning and innovation; independence from vendor; low cost). This is best done by stimulating the discussion on the subject, through seminars, conferences and open discussion groups. Specific courses on OS topics can help them gain official recognition.

Several examples of single universities or associations of universities committed to Open Source can be found in dedicated publications or online resources (Axelerant 2018)).

One reason why the higher education system ought to show a positive attitude towards OS is that it cannot afford to stay behind. The OS approach is just an aspect of a general shift in educational theory where the learner is gaining a more autonomous role (Kop and Hill 2008). Young people are increasingly accustomed to network-based forms of learning, and if teachers don't keep up with the innovation students will find the experts they are seeking elsewhere (Kop and Hill 2008).

4.2.2 Use Open Education tools for teaching and research

Universities supporting the OS model can do more than just promote it. They can actively support the use of OS software and hardware both in teaching and research projects. There is currently a rich literature on the subject of Open Education and also a great deal of online resources (see, e.g., (Bacon and Dillon 2006; Butcher 2015)) that can be used for inspiration.

The first way of putting the OS approach into action is by using methods of network-based collaboration, a scheme that is central to the OS model. As illustrated in the section "Open Education" above, this can be accomplished by setting up projects that involve designing new OS software and/or hardware, or modifying existing items, with the help of collaboration environments that should be OSS themselves. An example is using a FLOSS learning management system (e.g. Moodle) for the teaching activities.

Teaching material from such projects can be shared using existing OE platforms (www sites, wikis, repositories), or a new platform can be created *ex novo*.

As for research work, it is common practice to carry it out in teams; universities can set up incentives for research projects where the subject is OS software or hardware.

4.2.3 Open Access publication

Universities are the primary sources of advanced knowledge. The majority of them are publicly funded, either directly or indirectly. In accordance with their mission, many of them are already committed to making as much as possible of what they produce available worldwide under an open access license. This can take the form of explicit rules requiring research funded by a university to be published open access.

Faculty and research staff are well aware that their work is already paid for by their salaries and grants and need not be further remunerated by copyright; and that, on the other side, free circulation of the material they produce will help them gain visibility and reputation.

Publication costs, in the form of the APC imposed by major publishers, are largely unjustified, given the high profits of these companies (Buranyi 2017). Universities and public libraries have been (partly) successful in negotiating with publishers more reasonable deals on APC and subscription prices, but only when negotiation is led by a group of representative and influential institutions of a whole country (Vogel and Kupferschmidt 2017).

4.2.4 Substitute proprietary software with FLOSS

There is a simple step universities can take toward the diffusion of FLOSS: they can adopt the policy of substituting proprietary software with FLOSS.

This is more effectively done in the teaching and research areas, where the attitude towards FLOSS is usually more positive, and contact with this kind of tools more likely to have already happened. However, the transition to FLOSS can be made in every branch of activity of a university, including administration and technical services, for the good reasons that are valid for any generic firm (Roumani et al. 2017) and especially in the public sector (Casson and Ryan 2006), and that have been outlined in the section "Features" above (again: reliability, flexibility, incentive for innovation, cooperative scheme, independence from vendor, low cost). A specially suited area of application is web services, because of the impact it has on both the general public and the market; perhaps it is not a coincidence that many reputed Universities use FLOSS web content creation systems like Drupal (Axelerant 2018). One prominet project is the Open Source University Alliance (OSUA 2018), a EU initiative aimed at creating a repository of open source IT tools for the use of Universities; the repository is scheduled to be launched in December 2018.

4.2.5 Potential difficulties and drawbacks

In drawing this picture one should not overlook difficulties that can arise in the diffusion of the OS model, and also consider some of the potential drawbacks of the model itself (Lakhan and Jhunjhunwala 2008). For example, it is apparent that in some cases migrating to a new tool may be difficult and require participants to **overcome some activation barrier** (Lakhan and Jhunjhunwala 2008). This is generally not true of e.g. software solutions that are already well-established and widespread, such as LibreOffice or Ubuntu Linux, that tend to assume a user interface most people recognize and are comfortable with; smaller projects, however, may be available in a form that is tailored to a restricted community of practice and need new users to be somehow introduced and instructed; in some cases, some elementary programming skills will need to be acquired. This extra effort must be taken into account and planned in advance, lest the project will not yield the intended result.

Another point to keep in mind is that, in spite of some people seeing the OS philosophy as little less than an apology of anarchy, its loosely-organized working scheme is always built around a **simple but robust set of rules** and the corresponding communication tools (Bacon and Dillon 2006). Freedom needs constant, active maintenance: this principle has been the basis for all successful OS projects (think of what would have been of wikipedia had it not been properly managed against vandalism, inappropriate or irrelevant content, or centrifugal tendencies).

5 Conclusions

The starting point of this paper is the widely shared view that for our world to be sustainable (a) a substantial effort from developed countries to help poorer ones is required; and (b) this help is best given by transferring capabilities, rather than goods, so that in the future disadvantaged communities will be able to provide those goods for themselves.

The extraordinary advances of the last decades in the ICT area have made the transfer of knowledge incredibly faster and more efficient than ever; but, at the same time, the economical and legal barriers to free flow of information have become stronger, and tend to maintain the current imbalance between developed and undeveloped world. We have analyzed an alternative approach, the Open Source model, which is based on the idea that knowledge, unlike tangible goods, is a resource that one can give away without being deprived of it, and therefore should be very easy to distribute largely and equally.

A critical review of the essential features of Open Source software (better termed as FLOSS) shows that the basic principles of FLOSS can be transferred, with minor changes, to other fields of human activity, such as hardware and intellectual work in general. The effects on the creation and diffusion of knowledge are expected to be similar, as illustrated by some examples. This scheme can be shown to be economically sustainable; indeed, in some cases, such as academic publishing, it may be more sustainable than the restricted-access scheme.

Our line of reasoning is completed by a discussion of how the Open Source model is relevant for higher education, and by an outline of some lines of action that universities can take to spread the debate about the Open Source model and put it into action.

Since the Open Source model has, potentially, a revolutionary impact on the current society, we should not expect it to spread freely and quickly. Its controversial points and many areas of conflict with the *status quo* (for example, with the publishing industry) need to be further studied and discussed.

5.1 A closing note

The lesson of this study can be expressed in the simple words of a well-known adage, that goes,

> "Give a man a fish and you feed him for a day. Teach a man how to fish and you feed him for a lifetime"

We may note in closing that even the concept of "teaching" still implies an asymmetry between those who hold the rights to the information and those to whom it is administered; what is actually needed is freedom: freedom of access and freedom of use.

Thus we might formulate the Open Source way to sustainability as a variant of the proverb above:

> "Teach a man how to fish and you feed him for a lifetime. Let *every* man *learn* how to fish, and you feed *the whole humanity* forever"

5.2 Acknowledgements

I am very grateful to Sandra Ristori and Ugo Bardi for reading the manuscript and giving valuable advice.

References

Aksulu, A. and Wade, M. (2010). A comprehensive review and synthesis of open source research. *Journal of the Association for Information Systems*, 11(11):576.

Appropedia (2018). W3Techs - extensive and reliable web technology surveys. `http://www.appropedia.org` (Last accessed 7/17/2018).

Aragona, F. (2005). Open Sourcing Appropriate Technology Part I. `https://agroinnovations.com/blog/2005/11/17/open-sourcing-appropriate-technology-part-i/` (Last accessed 10/4/2018).

Arduino (2018). `https://www.arduino.cc` (Last accessed 7/16/2018).

ARL (2018). Association of Research Libraries statistics. `http://www.arlstatistics.org` (Last accessed 7/24/2018).

Axelerant (2018). Open source in higher education: Top 10 universities. `https://www.axelerant.com/resources/articles/open-source-in-higher-education` (Last accessed 7/30/2018).

Bacon, S. and Dillon, T. (2006). The potential of open source approaches for education. *Futurelab Open Education Reports*. `https://www.nfer.ac.uk/media/1821/futl58.pdf` (Last accessed 6/29/2018).

Badamasi, Y. A. (2014). The working principle of an Arduino. In *Electronics, computer and computation (icecco), 2014 11th international conference on*, pages 1–4. IEEE.

Benkler, Y. (2002). Coase's Penguin, or, Linux and "The Nature of the Firm". *Yale law journal*, pages 369–446.

Benkler, Y. (2006). *The wealth of networks: How social production transforms markets and freedom*. Yale University Press.

Björk, B.-C. and Solomon, D. (2014). Developing an effective market for open access article processing charges. *Abgerufen am*, 22(2):2015.

Black Duck (2016). The tenth annual future of open source survey. *Black Duck Software*.

Blind, K. (2012). The influence of regulations on innovation: A quantitative assessment for oecd countries. *Research Policy*, 41(2):391–400.

BOAI (2002). Read the Budapest Open Access Initiative. `http://www.budapestopenaccessinitiative.org/read` (Last accessed 7/27/2018).

Bohannon, J. (2016). Who's downloading pirated papers? Everyone.

Boldrin, M. et al. (2009). Against intellectual monopoly. *Syracuse Sci. & Tech. L. Rep.*, 2009:130–130.

Boldrin, M. and Levine, D. K. (2013). The case against patents. *Journal of Economic Perspectives*, 27(1):3–22.

Boldrin, M., Levine, D. K., et al. (2008). *Against intellectual monopoly*, volume 78. Cambridge University Press Cambridge.

Bonaccorsi, A. and Rossi, C. (2003). Why open source software can succeed. *Research policy*, 32(7):1243–1258.

Boulanger, A. (2005). Open-source versus proprietary software: Is one more reliable and secure than the other? *IBM Systems Journal*, 44(2):239–248.

Brandt, W. (1980). *North-South: A Program for Survival*. Bandt Report. MIT Press.

Brandt, W. (1983). *Common crisis North-South: cooperation for world recovery*. Pan world affairs. Pan.

Brundtland, G. H. (1987). *Report of the World Commission on environment and development: "Our Common Future"*. United Nations. `http://www.un-documents.net/our-common-future.pdf` (Last accessed 4/17/2018).

Buranyi, S. (2017). Is the staggeringly profitable business of scientific publishing bad for science? *The Guardian*. 7/27/2017.

Butcher, N. (2015). *A basic guide to open educational resources (OER)*. Commonwealth of Learning (COL);.

Carmichael, P. and Honour, L. (2002). Open source as appropriate technology for global education. *International Journal of Educational Development*, 22(1):47–53.

Casson, T. and Ryan, P. S. (2006). Open standards, open source adoption in the public sector, and their relationship to Microsoft's market dominance. `https://ssrn.com/abstract=1656616` (Last accessed 10/4/2018).

Coppola, C. and Neelley, E. (2004). Open source-opens learning: Why open source makes sense for education. `http://hdl.handle.net/10150/106028` (Last accessed 10/5/2018).

Daley, W. (2014). In search of optimality: Innovation, economic development, and intellectual property rights. *Global Sustainable Development Report Prototype, Briefs, 2014*. `https://sustainabledevelopment.un.org/content/documents/5580Innovation,EconomicDevelopmer` (Last accessed 10/4/2018).

edX (2018). About Us. `https://www.edx.org/about-us` (Last accessed 7/16/2018).

FSF (2017). Free Software Foundation: the Free Software Definition. `http://www.fsf.org/philosophy/free-sw.html` (Last accessed 9/18/2018).

Ghosh, R. A., Glott, R., Krieger, B., and Robles, G. (2002). Free/Libre and Open Source Software: Survey and Study - Part 4: Survey of Developers. `http://www.infonomics.nl/FLOSS/report/FLOSS_Final4.pdf` (Last accessed 10/5/2018).

Gloor, P. A. (2006). *Swarm creativity: Competitive advantage through collaborative innovation networks*. Oxford University Press.

Google (2016). Google Summer of Code. https://summerofcode.withgoogle.com (Last accessed 7/16/2018).

Hagedorn, G., Mietchen, D., Morris, R. A., Agosti, D., Penev, L., Berendsohn, W. G., and Hobern, D. (2011). Creative commons licenses and the non-commercial condition: Implications for the re-use of biodiversity information. *ZooKeys*, (150):127.

Henry, C. and Stiglitz, J. E. (2010). Intellectual property, dissemination of innovation and sustainable development. *Global Policy*, 1(3):237–251.

Hess, C. and Ostrom, E., editors (2007). *Understanding Knowledge as a Commons*. MIT Press.

Jones, R., Haufe, P., Sells, E., Iravani, P., Olliver, V., Palmer, C., and Bowyer, A. (2011). Reprap–the replicating rapid prototyper. *Robotica*, 29(1):177–191.

Kohn, A. (1987). Studies find reward often no motivator. *Boston Globe*, 19:52–59. 1/19/1987.

Kohn, A. (1992). *No contest: The case against competition*. Houghton Mifflin Harcourt.

Kop, R. and Hill, A. (2008). Connectivism: Learning theory of the future or vestige of the past? *The International Review of Research in Open and Distributed Learning*, 9(3).

Krishnamurthy, S. (2005). An Analysis of Open Source Business Models. In Joseph Feller, Brian Fitzgerald, S. H. and Lakhani, K., editors, *Making Sense of the Bazaar: Perspectives on Open Source and Free Software*. MIT Press.

Lakhan, S. E. and Jhunjhunwala, K. (2008). Open source software in education. *Educause Quarterly*, 31(2):32.

Li, Z., Seering, W., Ramos, J. D., and Wallace, D. (2017). Why open source? exploring the motivations of using an open model for hardware development. In *Proceedings of the ASME*.

Long, P. D. (2002). Opencourseware: Simple idea, profound implications. *Syllabus*, 15(6):12.

Marsan, J., Paré, G., and Beaudry, A. (2012). Adoption of open source software in organizations: A socio-cognitive perspective. *The Journal of Strategic Information Systems*, 21(4):257–273.

Miller, B. P., Koski, D., Lee, C. P., Maganty, V., Murthy, R., Natarajan, A., and Steidl, J. (1995). Fuzz revisited: A re-examination of the reliability of unix utilities and services. Technical report.

Möller, E. (2007). Anonymous co-authors (2007ff) The case for free use: Reasons not to use a Creative-Commons-NC-License. http://freedomdefined.org/Licenses/NC (Last accessed 10/4/2018).

Möller, E. (2008). Definition of free cultural works vers. 1.1. http://freedomdefined.org/Definition (Last accessed 10/4/2018).

Mushtaq, U. and Pearce, J. M. (2011). Open source appropriate nanotechnology. In *Nanotechnology and global sustainability*, pages 220–245. CRC Press.

Odlyzko, A. (1997). The economics of electronic journals. *First Monday*, 2(8). http://firstmonday.org/ojs/index.php/fm/article/view/542 (Last accessed 7/27/2018).

OEC (2018). Open Education Consortium. http://www.oeconsortium.org (Last accessed 7/16/2018).

OEE (2018). Open Education Europa. http://www.openeducationeuropa.eu (Last accessed 7/16/2018).

OER Commons (2018). The OER Commons. http://www.oercommons.org (Last accessed 7/16/2018).

O'Hara, K. J. and Kay, J. S. (2003). Open source software and computer science education. *Journal of Computing Sciences in Colleges*, 18(3):1–7.

Open Design Foundation (2000). Open design definition, v. 0.2. http://www.opendesign.org/odd.html (Last accessed 4/5/2016).

OpenHub (2018). https://www.openhub.net/ (Last accessed 7/23/2018).

Opensource.com (2018). Education. https://opensource.com/education (Last accessed 7/16/2018).

OSE (2018). Global Village Construction Set - Open Source Ecology. https://wiki.opensourceecology.org/wiki/Global_Village_Construction_Set (Last accessed 7/16/2018).

OSHWA (2012). Open Source Hardware Association: OSH Definition. http://www.oshwa.org/definition/ (Last accessed 7/7/2018).

OSI (2007). Open source initiative: The open source definition. https://opensource.org/osd (Last accessed 4/22/2018).

OSI (2018). Open source initiative: Frequently asked questions: what is open source software? https://opensource.org/faq#osd (Last accessed 4/22/2018).

OSUA (2018). Open Source University Alliance. http://uni-foundation.eu/open-source-university-alli (Last accessed 10/4/2018).

Pankaja, N. and Mukund Raj, P. (2013). Proprietary software versus open source software for education. *American Journal of Engineering Research*, 2(7):124–130.

Pearce, J. M. (2007). Teaching physics using appropriate technology projects. *The Physics Teacher*, 45(3):164–167.

Pearce, J. M. (2012). The case for open source appropriate technology. *Environment, Development and Sustainability*, 14(3):425–431.

Perens, B. et al. (1999). The open source definition. *Open sources: voices from the open source revolution*, 1:171–188.

Picerni, A. and De Rossi, A. (2009). L'offerta open source in italia: analisi di un settore in evoluzione.

Pisanski, K., Sorokowski, P., Kulczycki, E., et al. (2017). Predatory journals recruit fake editor. *Nature*, 543:481–3.

Pomerantz, J. and Peek, R. (2016). Fifty shades of open. *First Monday*, 21(5). http://www.ojphi.org/ojs/index.php/fm/article/view/6360/5460 (Last accessed 7/7/2018).

Quilligan, J. (2002). *The Brandt Equation: 21 St Century Blueprint for the New Global Economy*. Brandt 21 Forum.

Raymond, E. (1999). The cathedral and the bazaar. *Knowledge, Technology & Policy*, 12(3):23–49.

Roumani, Y., Nwankpa, J., and Roumani, Y. F. (2017). Adopters' trust in enterprise open source vendors: An empirical examination. *Journal of Systems and Software*, 125:256–270.

Sample, I. (2012). Harvard university says it can't afford journal publishers' prices. *The Guardian*, 24:2012.

Scardamalia, M. and Bereiter, C. (1991). Higher levels of agency for children in knowledge building: A challenge for the design of new knowledge media. *The Journal of the learning sciences*, 1(1):37–68.

Schumacher, E. F. (1973). *Small is beautiful: a study of economics as if people mattered*. Vintage.

Shieber, S. M. (2009). Equity for open-access journal publishing. *PLoS Biology*, 7(8):e1000165.

Stiglitz, J. E. and Greenwald, B. C. (2015). *Creating a Learning Society: A New Approach to Growth, Development, and Social Progress*. Columbia University Press.

Stokstad, E. (2011). network science: Open-source ecology takes root across the world. *Science*, 334(6054):308–309.

Thompson, C. (2008). Build it. share it. profit. can open source hardware work? *Work*, 10(08). https://www.wired.com/2008/10/ff-openmanufacturing/ (Last accessed 10/4/2018).

United Nations (2015). Sustainable Development Goals, 17 goals to transform our world. http://www.un.org/sustainabledevelopment/sustainable-development-goals/ (Last accessed 3/4/2018).

Vallance, R., Kiani, S., and Nayfeh, S. (2001). Open design of manufacturing equipment. cirp 1st international conference on agile, reconfigurable manufacturing. *Ann Arbor Google Scholar*.

Vogel, G. and Kupferschmidt, K. (2017). A bold open-access push in germany could change the future of academic publishing. *Science*, 23.

Weber, S. et al. (2000). The political economy of open source software. Technical report, UCAIS Berkeley Roundtable on the International Economy, UC Berkeley.

Wheeler, D. A. (2015). Why open source software. http://www.dwheeler.com/oss_fs_why.html (Last accessed 10/5/2018).

Zlotnick, F. (2017). Github open source survey 2017. http://opensourcesurvey.org/2017/ (Last accessed 10/4/2018).